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TITLE: Laser scanner incorporating variable focus mechanism for rapidly changing beam spot size

## ABPL:

An apparatus for rapidly varying the spot size of a scanned imaging laser beam comprises a focusing device (e.g. focussing and collimating lens arrangement) and a beam displacement control device (e.g. a rotary actuator scanner mirror or linear actuator). The beam displacement control device is operative to cause relative displacement between the laser beam and a selected one of a plurality of reflector element positions. Respective ones of the plurality of reflector positions are located at respectively different separation distances from the focusing device. As a result, in the course of traveling along an laser beam path, the laser beam is incident upon the focusing device and the reflector element, so as to be directed to a given spatial location along the path, whereby the laser beam has a resultant beam width that is dependent upon the separation distance between the selected reflector element position and the focusing device.

## BSPR:

The present invention relates in general to optical scanning apparatus and is particularly directed to an apparatus for scanning a laser beam, the spot size of which can be rapidly varied by an adjustable focus/defocus mechanism.

## BSPR:

Present day image reproduction systems, such as those employed in the entertainment industry, where large multicolor images may be recreated on a variety of image reproduction media, commonly employ one or more laser scanning devices to scan a modulated laser beam across an image projection surface. For optimal control of image reproduction, it is desirable to change the spot size (beam width) of the imaging laser beam and thereby the thickness of a line being imaged onto the reproduction surface. In the past, in order to vary line thickness, it was customary practice to rescan the beam across the imaging medium, with each subsequent scan being slightly offset from a previous scan, thereby widening or thickening the imaged line. Unfortunately, such a technique is extremely slow and detracts from the objective of rapidly displaying an image to a viewing audience.

## BSPR:

One proposal to solve this problem, described in the U.S. patent to M. Razzaghi, No. 5,274,492, entitled: "Light Spot Size and Shape Control for Laser Projector," involves the use of a flexible or deformable mirror to change the focus or spread of the scanning beam. Unfortunately, because the principal component employed in this system, the mirror element, is subjected to repetitious physical flexing and heating by the incident beam, it soon develops internal stresses, which not only modify the intended shape of the mirror, but limit its useful life. In addition, because of the heat-induced stress problem, such a scheme is limited to use with only relatively low energy lasers.

## BSPR:

In accordance with the present invention, the requirement to rapidly vary the spot size of a scanned imaging laser beam is successfully addressed, without suffering from the physical limitations of the above-described flexing mirror system, by means of a reflector translation device that is operative to controllably displace an optical beam reflector (e.g. a rotary actuator scanner

mirror) over a relatively short distance that is sufficient to change the effective travel path of the beam such that the focus of the beam and thereby its resulting spot size is rapidly changed.

BSPR:

Pursuant to a first embodiment of the present invention, an acousto-optic modulator imparts color and intensity modulation to a laser beam. Disposed in the travel path of the beam is a broadband polarizing, beamsplitter cube, which causes the first order beam output by the acousto-optic modulator to become horizontally polarized, so that the beam passes through the beamsplitter and is converted into circular polarization by an achromatic quarterwave retarder element. This circularly polarized beam is then focused by a focussing lens. The focussed beam is incident upon a scanned or rotated mirror of a closed loop rotary actuator scanner, which causes the mirror to rapidly translate the focussed beam onto a selected one of a plurality of retro-reflectors. The retro-reflectors are disposed at varying distances from the focusing lens.

BSPR:

Advantages of the second embodiment include the elimination of broadband optical isolators and a potential increase in efficiency. However, because of the additional geometry path considerations, the triangular arrangement is optically more complex and requires more alignment. The second embodiment may be modified by replacing the plane mirrors in the offset triangular path with spherical mirrors, thereby forming an asymmetrical telescope or down collimator. By proper selection of spherical mirror focal length, and appropriate spacing of the mirrors from the entrance lens, the exit lens may be omitted. Conversely, by proper selection of spherical mirror focal length, and appropriate spacing of the mirrors from the exit lens, the entrance lens may be omitted. As a further variation, a series of miniature lenses may be employed in place of the spherical mirrors.

BSPR:

An advantage of the third embodiment is that it achieves a very compact, easy to use optical system. Linear variable focus permits any spot size in the range to be accessed. Spot size can track a linear function, such as a linear waveform. Tracking spot size to a linear function is desirable for depth cueing applications, where the z-axis signal varies the spot size dynamically. Each of the embodiments of the invention is capable of focussing/defocussing a multiwavelength laser beam over a range of 1 to 50 milliradians, with access speeds in excess of 100 hertz, and may be used with high irradiance sources, up to 500 W/cm.<sup>sup.2</sup>.

DEPR:

Before describing in detail the new and improved laser scanning apparatus in accordance with the present invention, it should be observed that the invention resides primarily in what is effectively a beam focus adjustment mechanism, that is incorporated within the output path of a collimated laser source. The source of the laser beam itself and the scanning device components per se are unaffected by the focus adjustment mechanism and, per se, are not considered part of the invention. Consequently, the manner in which the present invention is integrated in the optical path of the scanning elements of the overall system have been illustrated in the drawings in readily understandable block diagram format, which show only those specific details that are pertinent to the present invention, so as not to obscure the disclosure with details which will be readily apparent to those skilled in the art having the benefit of the description herein. Thus, the block diagram illustrations are primarily intended to illustrate the major components of the system in a convenient functional grouping, whereby the present invention may be more readily understood.

DEPR:

Referring now to FIG. 1, a first embodiment of the present invention is diagrammatically illustrated as comprising an acousto-optic modulator 11, which is operative to impart color and intensity modulation to an incident laser beam 13 travelling along a laser beam travel path 15. Disposed in travel path 15 is a broadband polarizing, beamsplitter cube 21. The first order beam output by modulator 11 is horizontally polarized, so that it passes through beamsplitter 21 and is incident upon an achromatic quarterwave retarder element 23, which converts the linearly polarized light beam to into circular polarization. In lieu of using a separate beamsplitter and achromatic quarterwave retarder element, an

integrated polarizing beamsplitter/waveplate optical isolator may be employed. This circularly polarized beam at the output of quarterwave retarder element 23 is then focused by a focussing lens 25. (As a non-limiting example, lens 25 may comprise a 200 mm focal length lens.)

DEPR:

The embodiment of FIG. 2 may be modified by replacing the plane mirrors 53 and 63 used in the offset triangular path with spherical mirrors, thereby forming an asymmetrical telescope or down collimator. By proper selection of spherical mirror focal length, and appropriate spacing of the mirrors from entrance lens 51, exit lens 52 may be omitted. By the same token, by proper selection of spherical mirror focal length, and appropriate spacing of the mirrors from exit lens 52, entrance lens 51 may be omitted. As a further additional variation of such a modified embodiment, a series of miniature lenses may be employed in place of the spherical mirrors, which will realize the same optical result.

DEPR:

Experimental variation of the defocusing beam of the foregoing embodiments has revealed that the variation of intensity as a function of beam diameter becomes more readily apparent when a range of greater than 10:1 is used. Moreover, when the resultant beam is deflected (as with laser vector graphics), variations in intensity as a function of relative velocity become more apparent with the lower irradiance, large spot size. At 50 milliradians divergence, this characteristic is clearly discernable, and requires compensation.

DEPR:

The foregoing embodiments are capable of focussing/defocussing a multiwavelength laser beam over a range of 1 to 50 milliradians, with access speed in excess of 100 hertz, and may be used with high irradiance sources, up to 500 W/cm.<sup>sup.2</sup>.

DEPR:

As will be appreciated from the foregoing description, the requirement to rapidly vary the spot size of a scanned imaging laser beam is successfully addressed by the focusing/defocusing mechanism of the present invention, which does not suffer from the physical limitations of the above-described prior art flexing mirror system. Through the use of a reflector translation device, the invention is operative to controllably displace an optical beam reflector (e.g. a rotary actuator scanner mirror or linear actuator) over a relatively short distance that is sufficient to change the effective travel path of the beam such that the focus of the beam and thereby its resulting spot size is rapidly changed.

CLPR:

17. A laser beam scanning apparatus comprising a laser source which outputs a collimated laser beam, a device for controlling the beam width of said laser beam comprising a focusing device having a prescribed focal length, and a beam displacement control device which is operative to cause relative displacement between said laser beam and a selected one of said plurality of reflector element positions, respective ones of said plurality of reflector positions being located at respectively different separation distances from said focusing device, so as to cause said laser beam to be reflected from a reflector element provided at said selected one of said plurality of reflector positions, whereby, in the course of traveling along an laser beam path, said laser beam being incident upon said focusing device and said reflector element so as to be directed thereby to a given spatial location along said path, so that said laser beam has a resultant laser beam width that is dependent upon the separation distance between said selected one of said plurality of reflector element positions and said focusing device, and a multidimensional scanner which scans said resultant laser beam across an imaging surface, and wherein said beam displacement control device includes a linear actuator which is operative to cause linear displacement of said reflector element along the path of said laser beam to said selected one of said plurality of reflector positions, so as to cause said laser beam to be reflected from said reflector element and impinge upon said focusing device.